Protostellar Disk Eruptions

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Abstract: There is mounting evidence that circumstellar disks of YSOs become unstable every now and then, causing outbursts known as FU Ori phenomenon. Such an explosive event will presumably alter the disk and its envelope considerably. Signs of past outburst activity were identified for a few objects. Moreover, indications for an intermittent accretion behavior were found. The eruptions of protostellar disks might have serious implications for planet formation.

Introduction

Naturally, astronomy has its longest record in the visible. However, stars are born enshrouded in gas and dust. Only after the loss of the envelope their optical variability can be studied. Thus, the knowledge of protostellar variability is biased towards the end of star formation. During this phase, FU Ori (Fuor) outbursts were witnessed and recognized as extreme accretion events [1], likely driven by a circumstellar disk instability [2]. Only now, the wealth of IR data allows us to address this issue for earlier epochs of stellar birth [3, 4, 5].

Signs of a violent past

Fuors were found to be associated with ring- or arc-shaped nebula, thought to result from scattering in wind-blown cavities [6]. In fact, a new class of nebulae for which the star is on the periphery of a nebulous ring was introduced earlier [7]. However, no conjecture was made concerning its origin. In his seminal paper, Herbig envisaged that the strong but short-lived Fuor wind will lift-off dust, leading to scattering nebulae. The presence of dust arcs surrounding V1331 Cyg supports this view [8]. The ejection scenario was confirmed by the detection of an expanding CO ring associated with V1331 Cyg [9]. Notably, the molecular gas encompasses the dust arcs, indicating different expansion speeds. This results from the dependence of the acceleration on cross section and mass as well as the brief wind action.

Nebula expansion

Morphological changes of YSO nebulae are common. This is particularly valid for Fuor nebulae as revealed by a comparison of DSS and DSSII images. The ring-like geometry is well suited to trace expansion by estimating a possible radius change. Fig.1 shows the results for the HBC 491 nebula, derived using two methods, ring fits to the red DSS and DSSII images, and a least-squares morphing of the latter. Both yielded consistent values which prove the expansion despite the coarse pixel scale thanks to the epoch difference of 35yr. Thus, although HBC 491 does not show P Cygni lines which would qualify this star as a Fuor, an eruption can be dated which happened ~1500yr ago. Moreover, the star drives an H_2 flow [10] which indicates an intermittent accretion/collimation behavior.

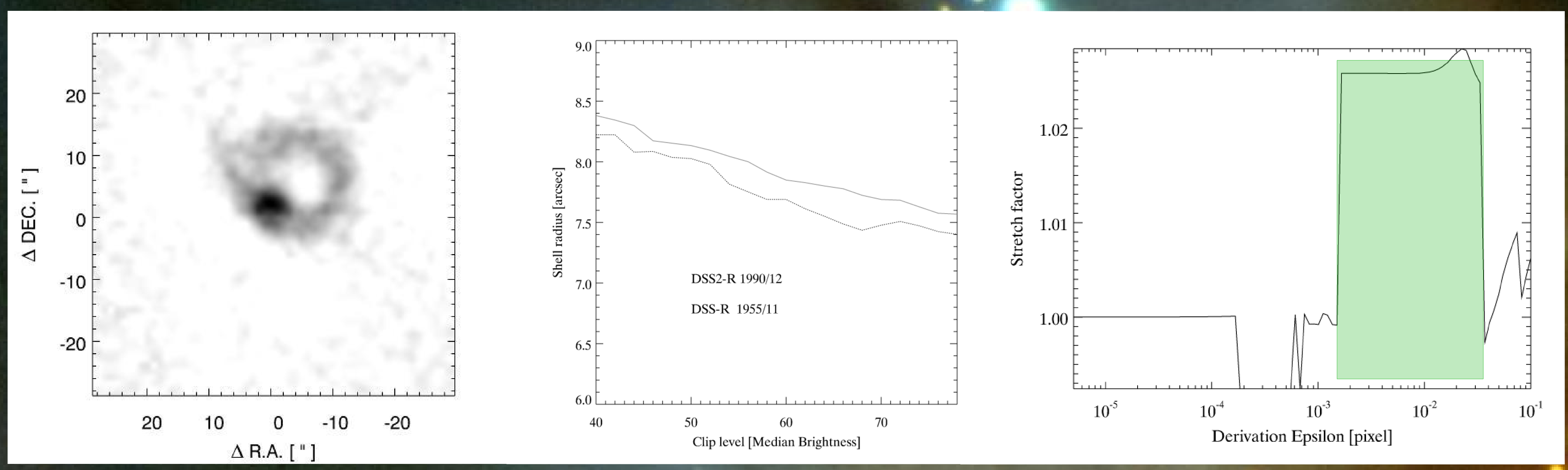

Fig.1 Left - DSSII R image of HBC 491. Center – Radii of fit ring fits in dependence on brightness clip level. Right – Stretch factor for the least-squares morphing in dependence on the parameter for computing the derivation. The green area marks the range where χ^2 attains its minimum.

Younger objects

The smaller epoch difference of IR observations implies that a similar analysis for embedded YSOs requires high-resolution imaging. A suitable target is HBC 363 which faded considerably during recent years, accompanied by spectral changes [11]. Fig.2 shows the NICMOS image (courtesy D. Padgett) with superimposed IRCAM3 contours. No proper motion is evident within 10yr. IRAC and UKIDSS H_2 imaging reveal that it drives an outflow as well. The expansion can also be traced by the Doppler shift of scattered line photons. This will be attempted for the "Diamond Ring Star" [12] by means of IFU spectroscopy at the ESO VLT. The analysis of ISAAC spectra of this source confirmed the presence of an H_2 jet. A third object was identified on a wide-field NIR image of the Flame nebula (background, courtesy D. Thompson).

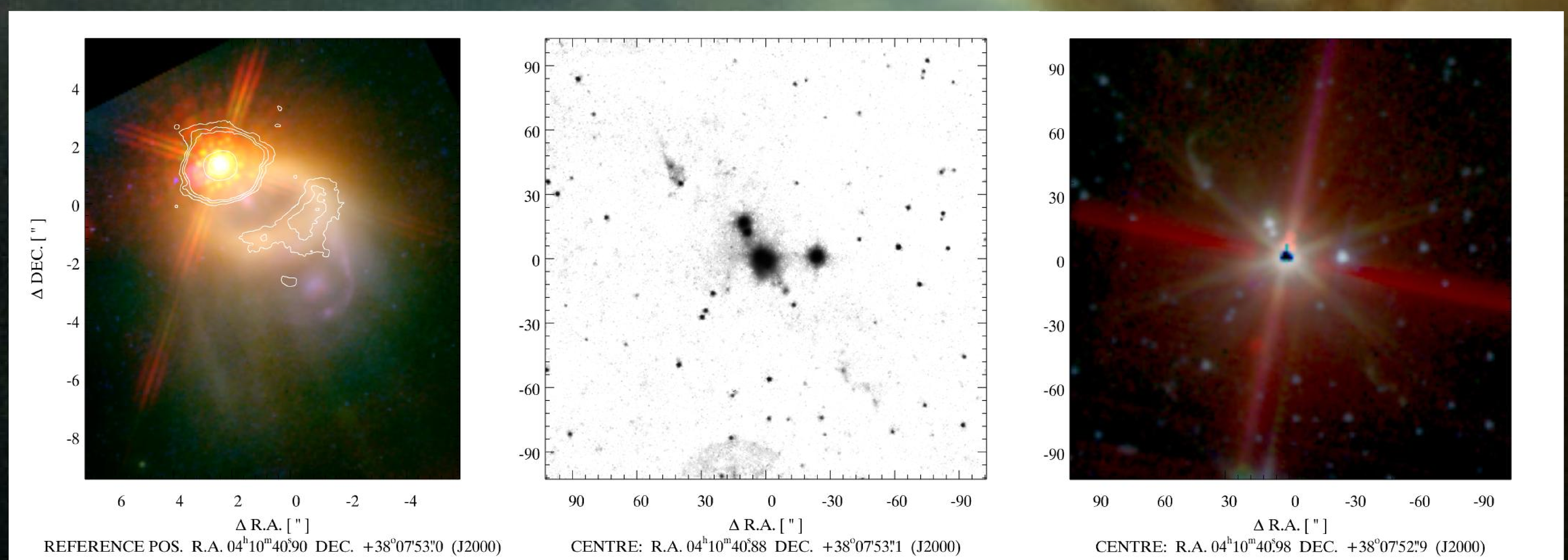

Fig.2 Left - NICMOS image of HBC 363 with superimposed IRCAM3 K contours at [1, 2, 3, 50, 100] σ. Center – UKIDSS H_2 image. Right – IRAC image based on 5.8, 4.5, and 3.6µm frames.

Nebula properties

The Fuor wind interacts with the YSO disk/envelope and blows out dust along the symmetry axis. However, only the nebula associated with the blue-shifted outflow lobe is observed. The low backscattering efficiency of dust grains [13] as well as extinction by the disk/envelope lead to a much dimmer counterpart. Furthermore, a ring-like morphology points to an inclination close to pole-on, explaining its rare occurrence. A first modeling attempt is based on an ad-hoc modified density structure of the envelope. Fig.3 shows the result of a Monte-Carlo ray-tracing simulation using the code of Whitney et a. [14].

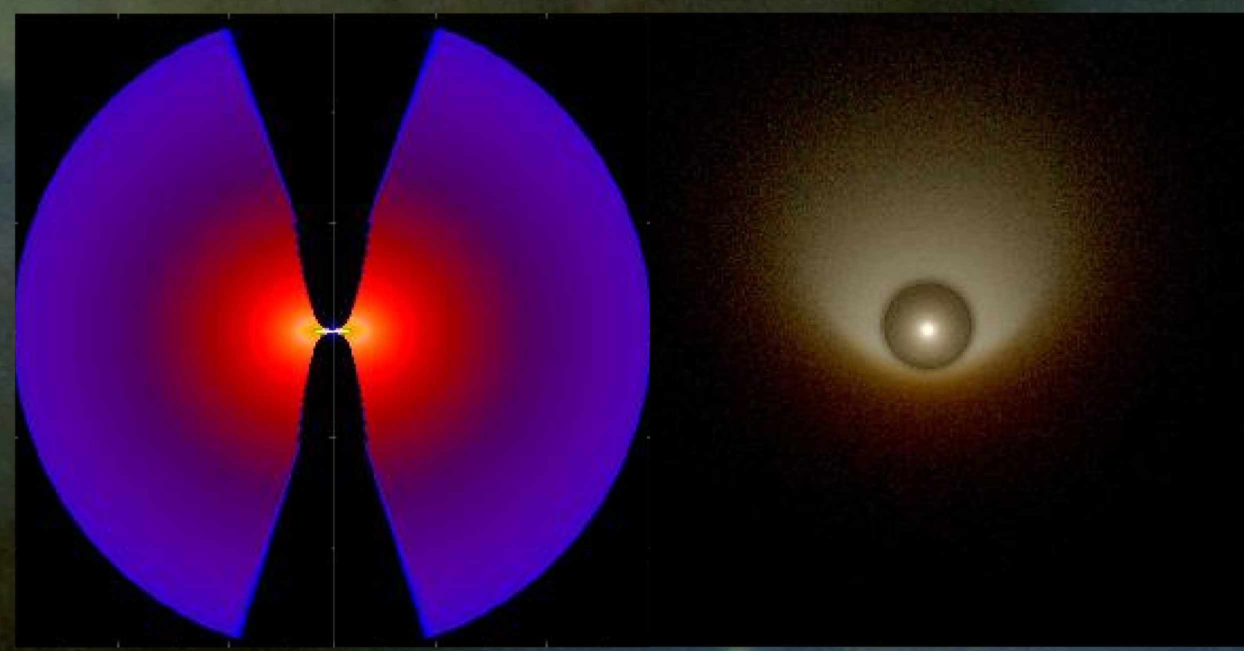

Fig.3 Left – Modified YSO density distribution assuming a widening of the inner envelope by the wind. Right – Synthetic KHJ image for an inclination of 15°.

Implications

The a-posteriori identification of YSO outbursts helps to pin down the frequency and origin of such events. Recent Fuor spectroscopy provided evidence against the thermal disk instability as a cause [15] and for a planet plunging event [16]. This is consistent with the accretion burst mode scenario [17] (Fig.4), where envelope infall drives the disk gravitationally unstable, leading to protoplanetary bodies which are steered inwards by gravitational torques, and become eventually accreted. Whether this is indeed the case or not, protostellar outbursts are a clear sign that circumstellar disks are more dynamic than commonly appreciated. The warm Spitzer mission has the potential to improve our knowledge on YSO variability considerably [18].

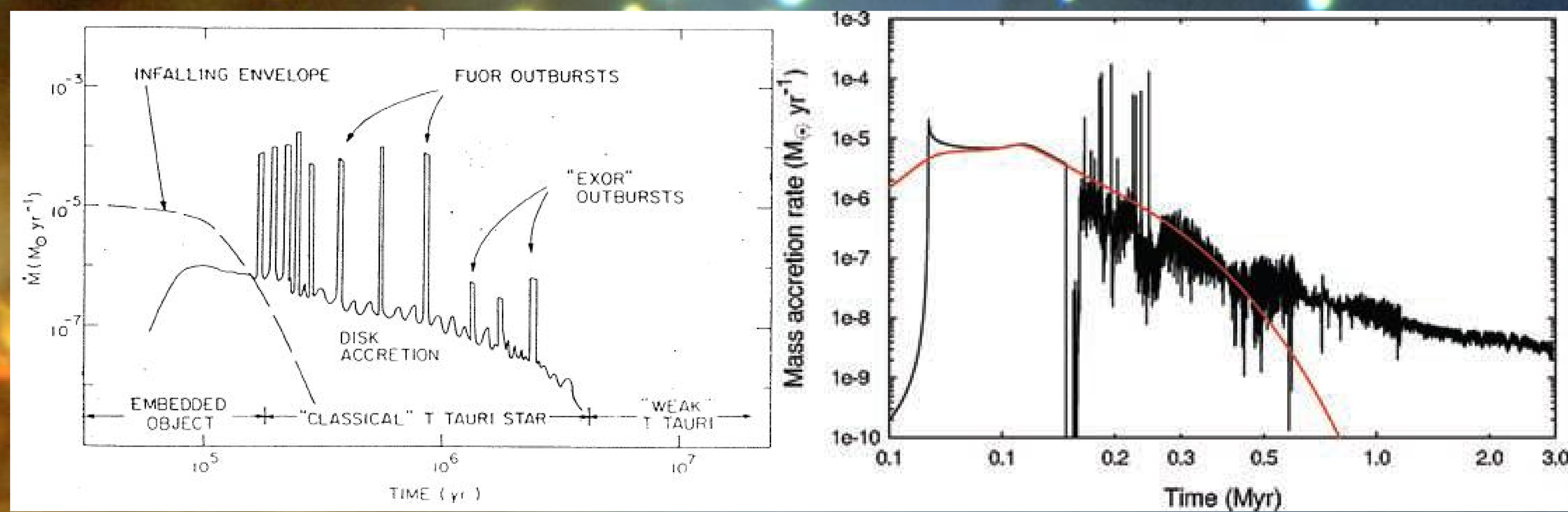

Fig.4 Temporal evolution of the YSO accretion rate. Left – Sketch from [2]. Right – Results of numerical simulations from [17]. The red line marks the mass infalling rate onto the disk.

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